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Poor energy ratings when appliances convey?

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ABSTRACT

Conveyance, i.e., leaving one's appliance in the dwelling when moving out, shortens the expected length of ownership of an appliance and may therefore lead to the purchase of less energy-efficient appliances. Employing a demographically representative survey in Spain, this paper uses statistical-econometric analyses to explore the effects of conveyance on stated adoption of energy-efficient appliances (refrigerators or fridge-freezer combinations, freezers, dishwashers, and washing machines). The findings suggest that the take-up of energy-efficient appliances is on average about 8%-points lower when appliances convey. In addition, conveyance appears to have comparable effects for renters and homeowners. These findings therefore suggest that conveyance contributes to explaining the energy efficiency paradox. Finally, the results appear robust to a series of robustness checks involving alternative assumptions about the distribution and data generating process, the specifications of the dependent variable, and the handling of missing values. They also provide insights for policy-making.

1. Introduction

Many attempts have been made to explain the energy efficiency paradox, according to which individuals and organizations fail to adopt energy-efficient technologies even though these appear profitable (e.g., Gerarden et al., 2015; Gillingham and Palmer, 2014; Jaffe and Stavins, 1994; Sorrell et al., 2004). Conveyance, i.e., leaving one's appliance in the dwelling when moving out, has recently been suggested as one of the factors that could help explain this paradox. Focusing on homeowners, Sandler (2018) suggests that conveyance may lead them to purchase less efficient appliances because it shortens the expected length of ownership of the appliance. Unless the value of an energy-efficient appliance is fully capitalized into the real estate sales price, the present value is lower than what it would be if the appliance had been kept for its entire useful lifetime. Asymmetric information and transaction costs (e.g., for working out detailed contractual arrangements, or for verifying energy performance of the appliance stock) that could lead to incomplete contracts (e.g., Schleich et al., 2019a) appear to be underlying sources of this negative effect of conveyance on the energy performance of appliances. Similar to the familiar landlord-tenant problem (e.g., Davis, 2011), these factors prevent the seller and buyer of a dwelling to enter into a contract which guarantees that the seller can fully recover investments in energy-efficient appliances. As Sandler (2018) notes, the capitalization may be incomplete because housing prices are typically rounded off to the nearest thousand dollars, whereas the differences in costs of energy-efficient versus non energy-efficient appliances are at most a few hundred dollars. In addition, the capitalization may be incomplete if the new owner values energy efficiency less than the seller, that is, if the preferences (e.g., for energy use) of the original and new owners differ, which is likely. For instance, Houde (2016) finds that household valuation of energy efficiency in appliances varies substantially.

To the best of our knowledge, only two empirical studies have been conducted on the impact of conveyance on the adoption of energy-efficient appliances (Sandler, 2018; Schleich et al., 2019a). Both studies focus on the effect of conveyance for homeowners in the USA. In the first study, Sandler (2018) finds that when appliances are likely to convey, households purchase less expensive refrigerators and washing machines. Hence, conveyance may prevent capitalization of premium features of appliances. In addition, Sandler (2018) finds "suggestive evidence" that conveyor households purchase smaller and less-fully featured refrigerators, which may incidentally result in lower energy consumption. In the second study, Schleich et al. (2019a) strive through a choice experiment to disentangle homeowners' willingness-to-pay for energy efficiency compared to other quality and performance attributes of refrigerators. They find that conveyors are more likely to choose a smaller refrigerator from a less well-known brand and with lower

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customer ratings, but find no direct effect on willingness-to-pay for energy efficiency. The authors speculate that in practice, conveyance might not directly affect the adoption of energy-efficient appliances but affect it indirectly through the choice of lower quality appliances, which are also less likely to be energy efficient.

Overall, these initial studies suggest that conveyance is likely to affect appliance choice and may have direct and indirect effects on energy efficiency adoption; these studies also call for more research on this issue. As noted above, both studies focus on the same market (USA) and exclusively on homeowners; yet, statistics show that renters are more likely to move than homeowners: moving rates of 21.7% for renters versus 5.5% for homeowners in 2017 in the USA (MoveOrg, 2019); moving rates of 43.3% for renters and 22.1% for homeowners with a mortgage for the period between 2007–2012 in the European Union (Eurostat, 2019a). Because conveyance only can occur for movers, studying its effects for renters and not only homeowners appears particularly relevant; further, it appears important to focus on actual adoption (unlike Schleich et al. (2019a) stated intentions in a choice experiment).

To conclude, in this paper we empirically analyze the effects of conveyance on the adoption of energy-efficient appliances for renters and homeowners, relying on an original demographically representative household survey in Spain. We only focus on appliances that were actually purchased by the households surveyed, thereby avoiding to capture effects for renters that would be due to split incentives (when landlords purchase appliances for renters). Our study allows the explicit comparison of the effects for renters and homeowners, and a test of the effects of conveyance on households' adoption of energy-efficient appliances. Identifying these effects appears particularly relevant from a policy standpoint since it could provide further insights into the underlying causes of the energy efficiency paradox.

The remainder of the paper is organized as follows: Section 2 describes the statistical methodology and the data. Section 3 presents and discusses the results. The final Section 4 concludes and provides policy implications.

2. Methodology and data

This section first presents the econometric model used to estimate household adoption of energy-efficient appliances. Then, we describe the survey and the variables used in the multivariate analysis.

2.1. Econometric model

We employ standard regression analysis to analyze the relation of conveyance and other covariates with the adoption of energy efficient appliances in a multivariate framework. Specifically, we run a binary response model:

$$y_i = \begin{cases} 1 & if\ y_i^* > 0 \\ 0 & otherwise \end{cases} \quad (1)$$

$$y_i^* = \beta X_i + \varepsilon_i, \quad (2)$$

where i indexes the individual household, β stands for a vector of coefficients, y_i^* is the latent variable (here: utility derived from adopting an energy efficient appliance), and X_i denotes a vector of explanatory variables containing an indicator for conveyance of appliances together with a set of covariates.[1] Finally, ε_i captures the error term. Because we assume ε_i to follow a logistic distribution, we estimate a standard logit model.

[1] Thus, the model abstracts from a potential endogeneity problem, i.e., unobserved factors may affect both energy efficiency and conveyance of the appliance.

2.2. Data

Our empirical analysis relies on original data collected through an online survey among 3898 households in Spain. This survey was implemented in March 2016 by NETQUEST via computer-assisted web interviews (CAWI) using an existing household panel. The survey participants were selected via quota sampling to be demographically representative in terms of gender, age (older than 18 years), and regional population distribution. Eligibility was limited to participants who were involved in their household's decisions for utilities, heating, and household appliance purchases. The original English survey was translated into Spanish by a Spanish translator; the quality of the translation was checked through native Spanish-speaking colleagues with minor adjustments made before distributing the survey. 4824 participants started the survey; the majority of the drop-outs happened in the beginning of the survey due to quota and study requirements (we eliminated respondents who reported living in a dormitory or military housing, as well as those who were not in charge of utility and appliance purchases). All participants received a fee for their participation (those eliminated after the initial quota questions received a minimal fee, while those who completed the survey received the full fee). This left us with a sample of 3898 observations.

After the initial quota questions, the survey assessed respondents' moving history and intentions, adoption of energy-efficient appliances (refrigerators or fridge-freezer combinations, freezers, dishwashers, and washing machines), dwelling characteristics, as well as individual characteristics such as environmental attitudes. The questionnaire finished with detailed socio-demographic questions in addition to those asked earlier for the quota qualification. To limit recall bias, we only included participants who were involved in an appliance purchase decision in the five years preceding the survey. Our final sample therefore includes 1844 observations.

2.3. Variables

We first present the dependent variable and then explain the explanatory variables in detail, including a variable reflecting the role of conveyance, and a set of covariates.

2.3.1. Dependent variables

To construct the dichotomous dependent variable (*toprated*), we use participants' stated adoption decisions on household appliances. Survey participants (homeowners and renters) who had purchased a new appliance (i.e., refrigerator or fridge/freezer combination, freezer, dishwasher, washing machine) in the five years preceding the survey were asked to report the EU energy label of the last appliance purchased. The four categories shown were: A+++ or A++, A+ or A, B or C, D or E. The original energy efficiency classes, as established in the EU "Energy Labelling Directive" (92/75/EEC), rated appliances from A to G, with A being the most energy efficient, and G being the least energy efficient class. To keep up with progress in energy efficiency, the scheme was revised, and the new classes A+, A++ and A+++ were introduced from 2010 on (Directive, 2009/125/EC)[2]; as a consequence, the new labels were available during the entire time frame used for our study (2011–2016), whereas appliances rated F and G were no longer on the market. For appliances in the highest label category (A+++ or A++), *toprated* was set equal to 1. For appliances categorized as A+ or lower, or if respondents did not know the label (ca. 13%), *toprated* took on the value of 0.[3]

[2] In early 2019, the European Commission decided to reintroduce the original A-G scale for future labels, mainly because it was easier to understand for consumers than the revised scheme.

[3] In section 3, we report findings on robustness checks which suggest that our results are not sensitive to this assumption.

2.3.2. Explanatory variables

To capture the effects of conveyance on the energy efficiency performance of the household's latest appliance purchase, we created a dummy variable, *convey*, to distinguish conveyors from non-conveyors in the econometric analysis. Conveyers are defined as respondents who stated that they would likely leave their appliance in the dwelling when they left their current dwelling. *Convey* takes the value of 1 for conveyors, and 0 for non-conveyors. Thus, we are particularly interested in the statistical significance, sign, and magnitude of the coefficient associated with *convey*.

Given the study's focus on conveyance, as well as on the comparison between renters and homeowners, it appears essential to independently measure moving intentions as well as ownership status of the dwelling.

When studying conveyance, moving intentions appear particularly important because appliance conveyance can only occur if households move. When moving out, households may take their appliances along with them, sell them on the second-hand market, dispose of them, or leave them either with the landlord or the next renter/owner of the dwelling (i.e., convey) – possibly in return for some remuneration. Except for the first option, each of these options may lead the original purchaser to abstain from acquiring an energy-efficient appliance because they may all prevent full capitalization of the added value of energy-efficient appliances. Only a few empirical studies have controlled for the effects of moving on the adoption of energy-efficient technologies. In Qiu et al. (2014) work, the probability of moving in the following five years was not found to have an effect on the presence of energy-efficient appliances for homeowners in Arizona and California. However, the authors did not account for conveyance nor assess adoption (the appliances may have been purchased by the previous owner). Our analysis includes the dummy variable *move*, which indicates whether households are likely to move in the next five years. This allows us to control for moving-related effects on energy efficiency of appliances which are not related to conveyance.[4]

Empirical analyses often find renters to be less likely than homeowners to adopt energy-efficient technologies (e.g., Davis, 2011; Ameli and Brandt, 2015; Krishnamurthy and Kriström, 2015; Schleich et al., 2019b). This result is typically explained through the landlord-tenant problem, i.e., the fact that because of split incentives, investors in energy-efficient technologies may not be able to appropriate the benefits of the investment; if the landlord provides the technology but the tenant benefits from a smaller energy bill, the landlord has no financial incentive to invest in energy-efficient technologies which have higher upfront costs than non-energy-efficient technologies. In this research, we purposely rule out this explanation by only including renters who purchased the appliances themselves. As a consequence, any effects of renting would not be due to the landlord-tenant problem. Previous research has not investigated the effects of renting beyond the landlord-tenant problem. By including the dummy variable *renter*, which takes the value 1 if the respondent rents his/her dwelling and 0 otherwise, our analysis can capture the effects of renting on the energy efficiency of appliances, which are attributable to renting per se, but not to conveyance (or moving).

The remaining covariates used as explanatory variables have typically been included in similar empirical studies on household adoption of energy-efficient technologies and reflect household characteristics, dwelling characteristics, and individual attitudes towards the environment. We also included product-category dummies to capture differences across appliances. This rich set of covariates aim to identify the effects of conveyance on the adoption of energy-efficient appliances and to mitigate a potential omitted variable bias.

The extant empirical literature typically finds a positive correlation of household *income* and the purchase of energy-efficient technologies (e.g., Michelsen and Madlener, 2012; Ramos et al., 2015; Schleich, 2019; Schleich et al., 2019b; Trotta, 2018) because, for instance, more affluent households are less likely to suffer from capital constraints. In the empirical specification, we used a dummy variable which we set equal to 1 if the household net income was above the country median. Because about one quarter of respondents failed to report their income category, we included a dummy variable (*income_miss*) which we set to 1 for those households; this procedure avoids losing a substantial number of degrees of freedom[5].

Likewise, empirical studies typically find a positive relation between *education* and household adoption of energy-efficient technologies (e.g. Di Maria et al., 2010; Michelsen and Madlener, 2012; Ramos et al., 2015; Schleich et al., 2019b) because a higher level of education is expected to lower the costs of information acquisition and to improve the processing of information (Schultz, 1975). For the econometric analysis, we employed a dummy variable which took on the value of 1 if the respondent's level of education exceeded the country median. For the approximately 1.4% of the participants who did not report their level of education, a dummy variable (*educ_miss*) was set to 1 indicating that information on the level of education for those households was missing.

The existing literature provides mixed results on the association of *age* and household adoption of energy-efficient technologies. While Ameli and Brandt (2015), or Schleich et al. (2019b) find older households to be more likely to adopt energy-efficient technologies, Michelsen and Madlener (2012), Mills and Schleich (2014), and Ramos et al. (2016) find the opposite. These inconsistent results may be explained by opposite effects of age on factors affecting energy efficiency adoption: on one hand, older age is typically associated with lower preferences for state-of-the art technologies as well as higher uncertainty about return on investment within one's lifetime (Carlsson-Kanyama et al., 2005); both of these factors would lower energy efficiency adoption. On the other hand, older age is also associated with patience (e.g., Tanaka et al., 2010), which may lead older households to accept longer payback times, and therefore lead to higher levels of energy efficiency adoption.

The majority of empirical analyses find pro-environmental attitudes to be positively related with household adoption of low-cost energy-efficient technologies such as light bulbs or appliances (e.g. Di Maria et al., 2010; Mills and Schleich, 2014; Ramos et al., 2016; Schleich et al., 2019b), but appear to be less relevant for predicting high-cost investments such as thermal retrofit or low-energy houses (e.g., Whitmarsh, 2009; Ramos et al., 2016; Olsthoorn et al., 2019), thus suggesting a trade-off between environmental and financial concerns. Our analysis employs *environmental identity* to capture environmental attitudes. To calculate *environmental identity,* we first took the average of 4 items[6] which were adapted from Whitmarsh and O'Neill (2010) and then transformed this average into a z-score.

Finally, the set of covariates includes dummies for the product category of the most recent appliance purchased. To avoid singularity of the regressor matrix, we excluded the dummy for the fridge/freezer combinations. Table 1 provides a more detailed description of each explanatory variable.

[4] Note that we assess the effects of conveyance and moving independently in our analysis. We reason that conveyance may affect purchase decision even if a respondent has no concrete plans to move. The simple fact to know that the appliance will stay in the dwelling if moving occurs should affect appliance choice because the possibility to move exists, even if moving in the next five years is not concretely planned. In section 3.3 we report findings from estimating a model which includes an interaction term between *convey* and *move*, thus allowing for the possibility that the effect of conveyance is stronger when respondents decide to move within the next five years.

[5] We checked the robustness of our findings to the inclusion of missing values on income (and also education). As summarized in the sub-section on robustness checks in section 3, our findings are robust, even if these observations are dropped.

[6] The items are provided in Table 1.

3. Results and discussion

We first briefly report descriptive statistics for the variables used in the multivariate adoption models. We then present and discuss in detail the results of the econometric analysis. Finally, we summarize the findings from a series of robustness checks.

3.1. Descriptive statistics

Table 2 displays the descriptive statistics of the dependent and explanatory variables used in the econometric analysis. The product category dummies at the bottom of Table 2 indicate that about 38% of the most recent appliance purchasing decisions involved fridge/freezer combinations, 36% washing machines, 19% dishwashers, and 7% freezers. About 62% of the appliance purchases were reported to be in the highest label category A+++ or A++. We further note that about 21% of the households in the final sample are renters. The share of conveyers is roughly 56%, which is higher for homeowners (60%) than for renters (42%). We also note that roughly 35% of the participants are planning to move within the following 5 years, with renters being more than twice as likely to do so compared to homeowners (59% versus 28%). As indicated by the standard deviations, for most variables there is considerable variation in the data.

3.2. Results from multivariate analyses

We report results from estimating a standard logit model using robust standard errors in Table 3. To allow for a meaningful interpretation of the findings, for the continuous variables (*age* and *environmental identity*) Table 3 displays the average expected marginal effects of the explanatory variables rather than the coefficients of the latent utility function described by equation (2). Similarly, for the dummy variables, Table 3 shows the expected discrete probability effects.[7]

Table 1
Description of explanatory variables.

Label	Description
Convey	Dummy = 1, if appliances convey.
Move	Dummy = 1, if the household is planning to move within the next 5 years.
Renter	Dummy = 1, if the household is renting the current dwelling.
Income	Dummy = 1, if household annual income (after taxes) is higher than the median. The survey used twelve income categories.
Income_miss	Dummy = 1, if household did not report income category.
Education	Dummy = 1, if level higher than median. Considered levels: no degree or certificate/trade or vocational certificate/high school or equivalent/higher education.
Educ_miss	Dummy = 1, if household did not report level of education.
Age	Respondent age in years.
Environmental identity	Score reflecting environmental identity. Constructed using the equally weighted responses to the subsequent scale items (1 = strongly disagree to 5 = strongly agree): "Please rate how much you agree with the following statements: (i) To save energy is an important part of who I am. (ii) I think of myself as an energy conscious person. (iii) I think of myself as someone who is very concerned with environmental issues. (iv) Being environmentally friendly is an important part of who I am."
Product category dummies	Dummies indicating whether most recent purchase was a refrigerator/freezer combination (*fridge* = 1), freezer (*freezer* = 1), dishwasher (*dishwasher* = 1) or washing machine (*washing* = 1).

Table 2
Descriptive statistics (N = 1844).

Variable	Mean	Std. Dev.	Min	Max
Toprated (A+++ or A++)	0.619	0.486	0	1
Convey	0.564	0.496	0	1
Move	0.346	0.408	0	1
Renter	0.211	0.408	0	1
Income	0.581	0.494	0	1
Income_miss	0.245	0.430	0	1
Education	0.682	0.466	0	1
Educ_miss	0.014	0.118	0	1
Age	38.326	11.861	18	98
Environmental identity [a]	0.000	1.000	−3.527	1.489
Fridge/freezer combo	0.381	0.486	0	1
Freezer	0.069	0.254	0	1
Dishwasher	0.189	0.391	0	1
Washing	0.361	0.480	0	1

[a] z-score of the variable was used.

Most notably, the results suggest that conveyers are associated with a statistically significantly lower propensity to have purchased an energy-efficient appliance than non-conveyers. The point estimate for the marginal effect of *convey* of −0.081 in Table 3 suggests that conveyance lowers the likelihood that a household's most recent appliance purchase was an energy-efficient one by 8.1%-points. Using the figure for the average rate of reported adoption of a top-rated appliance in Table 2, this translates into a reduction of about 13% (= −0.081/0.619).

Being a *renter* lowers the likelihood of having adopted an energy-efficient appliance by 10.1%-points. Similarly, expecting to *move* out of the current dwelling within the next five years lowers the likelihood of having purchased an energy-efficient appliance by 8.8%-points.

We now turn to the findings for the covariates, which are all statistically significant at least at the 5% level. Households with above-median *income* or *education* levels are found to exhibit a higher propensity to have adopted energy-efficient appliances than households with below-median income or education levels. The coefficients associated with missing responses for household income or for education level were not statistically significant. *Age* is positively correlated with the stated take-up of energy-efficient appliances. A higher *environmental identity* score renders the reported take-up of energy-efficient appliances more likely. For example, the likelihood of having adopted an energy-efficient appliance increases by 3.5%-points for a one-standard deviation increase in the environmental identity score.[8] Finally, the findings for the product category dummies suggest that the likelihood to have purchased a top-rated energy-efficient appliance is 18%-points lower when the last purchase was a freezer rather than a refrigerator (or fridge-freezer combination).

3.2.1. Test for heterogeneity of conveyance effect across homeowners and renters

To explore whether the effect of conveyance on the purchase of energy-efficient appliances differs between homeowners and renters, we estimated a model which includes an interaction term between *convey* and *renter*. The findings for this model suggest that the discrete probability effect for renters is about 5.6%-points larger (in absolute terms) than for homeowners. But this difference is not statistically significant.

[7] To test for collinearity, we calculated the variance-inflation factors (VIFs). The mean VIF is 1.26 and none of the VIFs of the individual variables exceeds 2. These figures are below the critical value of 10, which is often used as a benchmark. Therefore, our findings do not appear to suffer from collinearity problems.

[8] For z-scored variables like environmental identity, the standard deviation is equal to one. Hence, an increase by one unit corresponds to an increase by one standard deviation.

Table 3
Logit model results (average marginal effects and discrete probability effects) for purchasing energy-efficient appliances.

Variable	
Convey	−0.081***
	(0.023)
Move	−0.088***
	(0.025)
Renter	−0.101***
	(0.029)
Income	0.061**
	(0.031)
Income_miss	0.047
	(0.033)
Education	0.052**
	(0.025)
Educ_miss	0.021
	(0.097)
Age	0.003***
	(0.001)
Environmental identity†	0.035***
	(0.011)
Freezer	−0.182***
	(0.043)
Dishwasher	−0.003
	(0.031)
Washing	−0.008
	(0.026)
N	1844

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

3.2.2. Discussion of findings

We focus our attention on the findings that are new to the literature. First, our results suggest that for both homeowners and renters, conveyance is negatively related with the adoption of energy-efficient appliances. The scant previous empirical research on conveyance had only considered homeowners, while our results imply that this effect does not appear to differ between homeowners and renters. Our results suggest that when appliances convey, the incomplete capitalization problem generally identified by Sandler (2018) and Schleich et al. (2019a, b) for homeowners may also be at work for renters. Therefore, when renters leave their appliances with their landlord or with the subsequent renter, the reimbursement may not fully cover the extra purchasing costs for energy-efficient appliances because preferences differ, or – akin to the selling of houses – because the sales price of built-in-kitchen is rounded off. We also find that the effect of conveyance may be substantial. Our point estimate suggests that on average, the take-up of energy efficient appliances is about 8%-points lower when appliances convey.

In addition to the conveyance effect, we find distinct effects for the likelihood to move in the near future, and for being a renter on stated adoption of energy-efficient appliances. These effects for moving and renters have the same direction and are of comparable magnitude as the conveyance effect. Previous literature has not made these distinctions and we can only speculate on the underlying mechanisms.

We find that expecting to move has an effect on energy efficiency adoption independent both of whether appliances convey and of home ownership. This may be due to uncertainty about the next dwelling, where the appliance might or not fit (or which might even already have an appliance), uncertainty about one's needs in the future (for instance, when moving is due to a change in family composition), as well as uncertainty about the price to be obtained for the appliance if it has to be sold on the secondhand market. Overall, with or without conveyance, moving may therefore also generate a situation in which households are uncertain to be able to fully recover their investments. We are the first to investigate and show this effect as separate from other related effects (especially conveyance).

The effects of renting appear particularly interesting. As mentioned earlier, in this study we purposely focus on appliances that were actually purchased by the households surveyed, thereby avoiding to capture effects that would be due to split incentives (when landlords purchase appliances for renters). Therefore, the significant effects of renting are above and beyond those explained by probability to move (captured separately) and by conveyance. They may reflect what is known in the psychology literature as the "mere ownership effect", i.e., the fact that individuals behave differently and are generally more attached to material goods they own (Beggan, 1992). Because renters do not own their dwelling, they may not be as attached to it as homeowners and, therefore, may be less likely to psychologically and financially invest in it. Of course, at this point, this interpretation is speculative.

Similar to the study by Sandler (2018), since data availability does not allow us to disentangle energy performance from other appliance features, the observed correlations between conveyance and energy efficiency class may not be causal. For example, if more expensive, higher quality appliances are also more energy-efficient, conveyors may automatically purchase less energy-efficient appliances. That is, we cannot rule out that the negative effect of conveyance on energy efficiency adoption may be due to the fact that conveyors buy lower quality appliances and, as a consequence, less energy-efficient appliances.

Our findings for income, education, and environmental identity reported in Table 3 are in line with the thrust of the previous empirical literature on energy efficiency adoption. For age (for which the literature finds inconsistent results), we obtain a positive effect, in line with the results obtained by Ameli and Brandt (2015) and Schleich et al. (2019b). The findings that the likelihood of participants having purchased a top-rated energy-efficient appliance is substantially lower for freezers than for a refrigerator (or fridge-freezer combination) may be explained by the lower market availability of top-rated freezers compared to top-rated refrigerators or fridge-freezer combinations. For example, VKE/ARMIDES (2015) find that in 2014, depending on the product category, between 48% and 81% of the refrigerators or fridge-freezer models available in the EU were class A++ or A+++. In comparison, this share was 27% for chest freezers and 47%f or upright freezers.

3.3. Results from robustness checks

To assess the sensitivity of our findings, we carried out a series of additional analyses. The findings for these robustness checks are summarized in the following categories: (i) assumptions about the distribution and data generating process, (ii) alternative specifications of the dependent variable, (iii) including a conveyance-moving interaction term as an additional covariate, and (iv) the handling of missing values.[9]

3.3.1. Assumptions about the distribution and data generating process

First, we considered alternative distributional assumptions to the logit model. Estimating a probit model and a complementary log-log models lead to virtually identical results as those reported in Table 3. In addition, the AIC/BIC measures of fit were almost the same across the logit, probit and complementary log-log models. Finally, we note that running a simple linear probability model yields coefficients that are almost identical to the marginal effects and discrete probability effects reported in Table 3. Specifically, the point estimate for the slope coefficient associated with *convey* in the linear probability model is - 0.081 ($p < 0.01$), i.e., the same as the discrete probability effect for *convey*in Table 3.

In addition, we estimated an ordered logit model, which accounts for the fact that originally, participants' responses on the label class of their most recent appliance purchased were organized in four energy label categories and that these categories have a meaningful sequential order.

[9] To save space, we do not show the results of the robustness checks. They are available from the authors.

Based on the results of initial tests on whether the cutoff points differ, we merged two of the four categories and constructed three categories for the dependent variable: A+++, A++/A+, and A/B-E, with the latter category also including participants who indicated that they did not know the energy label of their last appliance purchase. Since the "parallel lines" assumption was violated for three variables (*income_miss, environmental identity, dishwasher and washing*), we estimated a generalized ordered logit model. The results for the point estimates of the discrete probability effects suggest that *conveyance* lowers the probability of participants reporting adoption of the highest energy label category (A+++ or A++) by about 7.9%-points ($p < 0.01$), which is almost identical to the corresponding finding (i.e., 8.1%-points) reported in Table 3. In turn, conveyers have about a 4.2%-point lower probability of reporting adopting the lowest energy label category (B-E) and about a 3.7%-point lower probability of reporting adopting the medium energy label category (A). The results for the covariates of the generalized ordered logit model are also very similar to those presented in Table 3. Overall, the results therefore appear stable across a variety of statistical models.

3.3.2. Alternative specifications of the dependent variable

To construct the dependent variable for the results presented in Table 3, we used respondents' answers to the question about the energy label category (A+++ or A++, A+ or A, B or C, D or E) of their last appliance purchased. In addition, the survey also included a question asking whether the last appliance purchased was a top energy efficient appliance. As an alternative specification, we used this question to construct the dependent variable. For this model, the findings suggest that conveyance lowers a household's probability to have purchased an energy efficient appliance by about 4.6%-points ($p < 0.05$). Thus, according to this specification, the effects of conveyance on the adoption of energy-efficient appliances is somewhat smaller than in the results presented in Table 3. However, we suspect that this alternative specification of the dependent variable is based on less precise responses and, in particular, that it is more prone to suffer from a social desirability bias. About 80% of the appliances purchased were reported to be top-rated energy-efficient appliances (compared to 62% using the EU label categories). Both figures exceed actual shares, but the error in the dependent variable is substantially smaller when the EU label categories are used.

Next, to explore the potential effects of recall bias, we only used appliance adoption decisions from the two years preceding the survey, i.e., 2014 or later (the results presented in Table 3 relied on adoption decisions from the five years preceding the survey). Limiting the sample in this way results in a loss of 833 observations (ca. 45%). The findings for this smaller sample, however, are almost the same as those reported in Table 3. In particular, the point estimate for the discrete probability effect of convey is - 0.073 and statistically significant at $p < 0.05$ (compared to - 0.081 in Table 3).

Overall, the results therefore appear to be robust to various specifications of the dependent variable.

3.3.3. Including a conveyance-moving interaction term as additional covariate

To test whether the effect of conveyance is stronger when respondents plan to move within the next five years compared to when they do not plan to move within the next five years, we included an interaction term between *convey* and *move* as an additional covariate in our econometric model. We ran two models, a logit model and a linear probability model. For both models, we find no evidence that the interaction terms has any effect and the results with and without interaction term are almost identical. For example, the P-value associated with the interaction term in the linear probability model is 0.47.

3.3.4. Handling of missing values

The results presented in Table 3 may be sensitive to our assumptions about missing values. We therefore estimated our model dropping all observations where values on household income were missing. This leads to a loss of 451 observations, but the findings are very similar to those shown in Table 3. In particular, the discrete probability effect for *convey* is - 5.6%-points ($p < 0.05$).

Finally, we estimated a model where we dropped observations of respondents who did not know the label class of their last appliance purchased. Estimating the model for this smaller sample (1599 versus 1844 observations) yields virtually identical results to those presented in Table 3. In particular, the discrete probability effect of *convey* is - 6.8%-points ($p < 0.01$).

In summary, our findings appear to be robust to alternative assumptions about the distribution and data generating process, the specifications of the dependent variable, including an interaction term for conveyance and moving as an additional covariate, and our handling of missing values.

4. Conclusions and policy implications

Conveyance, i.e., leaving one's appliance in the dwelling when moving out, shortens the expected length of ownership of the appliance and may therefore lead to the purchase of less efficient appliances. Yet, the empirical evidence on the effects of conveyance on household adoption of energy-efficient appliances is scarce and has been limited to homeowners in the USA. Employing a demographically representative survey in Spain, this paper uses statistical-econometric analyses of household adoption of appliances (refrigerators or fridge-freezer combinations, freezers, dishwashers, and washing machines). Unlike previous studies, our sample includes homeowners and renters. In addition to a negative effect of conveyance, we find distinct effects for the likelihood to move in the near future, and for being a renter on stated adoption of energy-efficient appliances. These effects for moving and renters have the same direction and are of comparable magnitude as the conveyance effect. Our findings appear robust to a series of robustness checks involving alternative assumptions about the distribution and data generating process, the specifications of the dependent variable, and our handling of missing values. The findings also provide insights for policy-making.

4.1. Main findings

Our key result suggest that the take-up of energy-efficient appliances is on average about 8%-points lower when appliances convey. For our sample, this corresponds to a 13% decrease in the adoption of energy-efficient appliances. Thus, conveyance of appliances appears to help explain the energy efficiency paradox, and may noticeably and negatively affect the chances to achieve national and EU-wide energy efficiency and climate targets because electric appliances (and lighting) currently account for about 14% of final residential energy use in the EU (Eurostat, 2019b). An increase in mobility (e.g. across regions, or from rural to urban areas) is expected to intensify the effects of conveyance in the future. We further find no difference in the effects of conveyance between homeowners and renters. Thus, similar to when homeowners sell their dwelling, when renters leave their appliances with their landlord or with the subsequent renter, the reimbursement may not fully cover the extra purchasing costs for energy-efficient appliances. Therefore, the original buyer will not be able to enjoy all the benefits and may opt for a less energy-efficient appliance.

Our empirical findings are derived for Spain, but we expect them to also be relevant for other countries where appliances convey. The findings for renters should be particularly relevant for countries with high shares of renters such as Germany, where currently only about 51% percent of households own their current residence (compared to 69% for the EU 28 average, or 65% for the USA) (Statista, 2019a, b).

4.2. Policy recommendations

The first implication of our results concerns public policy. If conveyance leads households to undervalue future energy costs when purchasing appliances, policy interventions which increase the energy performance of the appliances bought would be desirable from a private and social perspective. Such interventions improve private and also social welfare because consumers save expenditures for energy use and because negative externalities associated with resource use and local and global emissions are lowered. Then, from a public policy standpoint, laws that make conveyance the default (as in many federal states in the USA) should be abolished. Of course, as any policy intervention, such a policy would also have to pass a cost-benefit test.

Where conveyance prevails, other measures might be called for. The first type of measures aims at facilitating the sale of used appliances at an appropriate price. Because of asymmetric information and transaction costs, the seller may not be able to signal the energy performance of a used appliance to a potential buyer. In this case, energy labels, which are supposed to deliver observable, uniform, and credible information on appliances' energy performance and costs (e.g., Truffer et al., 2001) may be a cost-effective measure. This assumes, of course, that the energy label remains attached to the used appliance and visible until sold. In addition, the energy label should provide energy costs (in €) instead of or in addition to energy use (in kWh). Such information is expected to help customers calculate the additional economic benefit of purchasing an energy-efficient appliance and hence to make a more informed decision. The current EU energy label, however, shows energy use but not energy costs. Likewise, the EU European decision of early 2019 to reintroduce the A-G labelling scheme (replacing the current scheme which goes to A+++) may help purchasers distinguish clearly between the most energy-efficient appliances.

Policy recommendations are less straightforward when the seller of a dwelling cannot fully recover the additional costs of an energy-efficient appliance because it is sold as part of a built-in kitchen and selling prices are rounded off. In this case, individual appliances could be sold as single items, but the transaction costs incurred may be prohibitive. More generally, establishing liquid second-hand markets for appliances akin to markets for used cars would lower search costs and could help match sellers of energy-efficient appliances with buyers who value energy efficiency highly.

The second types of measures aims at decoupling ownership of appliances from their services. For example, in line with current societal trends towards the renting economy, especially for durables (e.g., cars, bicycles), consumers could decide to rent rather than own major household appliances. From the perspective of a household, this might allow breaking the link between acquiring an appliance and the risk of recovering initial investment costs when expectations of moving shorten the expected usage time of the appliance.

Deciding which measures should be pursued in priority will likely require a deeper understanding of the factors underlying the observed negative impact of conveyance on the energy-efficiency of appliances. This was not the objective of our study and must be left for future research.

Finally, in addition to the conveyance effect, our findings suggest distinct and quantitatively relevant effects of the likelihood to move in the near future and of being a renter on the stated adoption of energy-efficient appliances. Future empirical studies exploring the factors related to the adoption of energy-efficient appliances should explicitly incorporate these factors and distinguish these effects to avoid confounding as well as omitted variable bias. The results also suggest the need for further research to understand the reasons for this "pure renting effect", so that effective policies towards renters can be developed. For instance, policies that raise the feelings of ownership of the appliances may be used to compensate for the low feelings of ownership of the dwelling.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Corinne Faure: Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing, Project administration, Funding acquisition. **Joachim Schleich:** Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing, Project administration, Funding acquisition, Formal analysis.

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